THE HORIZONTAL DISTRIBUTION OF ZOOPLANKTON IN KANEOHE BAY, OAHU, HAWAII

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HONOLULU, HAWAII   TECHNICAL REPORT NO. 23   DECEMBER 1970

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December 1970

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Technical Report Number 23

ABSTRACT

Samples were taken with the Longhurst-Hardy plankton sampler in Kaneohe Bay, Oahu, Hawaii, during 1969, to study the horizontal distribution of the zooplankton. Kaneohe Bay was divided into six different regions, and samples were taken in each region. The distributions of the zooplankton were analysed by computer for deviations from randomness, and these deviations were compared between regions.

It was found that two different types of distributions were present. First, some of the animals had distributions that did not deviate from randomness. Second, most of the animals were found to have distributions that did deviate from randomness. These distributions were of two types.

Several of the animals found in the Southern Sector of Kaneohe Bay were found to be associated with two bathymetric features, a patch reef and a relatively isolated cove. The associations of these animals with the bathymetric features is suggested as being of an active nature.

The remaining distributions showed a pattern of deviation from randomness which was attributed to the effect of mixing of different water masses during the tidal exchange of water between Kaneohe Bay and the ocean.

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INTRODUCTION

The non-randomness in the distribution of the zooplankton is one of the least understood and yet most widely discussed subjects in the field of biological oceanography. Haeckel (1890) first suggested that the assumptions of random distribution of zooplankton made by previous investigators were false. These criticisms were overlooked until Hardy (1936) presented convincing evidence that oceanic plankton were aggregated on scales of several or hundreds of miles. Barnes (1949) suggested that it was desireable to re-examine the assumptions that the zooplankton were randomly distributed after finding variations in zooplankton captures in a series of carefully controlled volumes of water.

There has been little study of the patterns of distributions of zooplankton on a scale smaller than several miles. Studies with plankton pumps (Barnes and Marshall, 1951; Cassie, 1959a, 1960) have indicated that on a scale of about 100 m. the zooplankton are clumped or aggregated far more often than they are evenly or randomly distributed. However, these studies with the plankton pump were in effect studying horizontal columns of water five to ten centimeters in diameter and one hundred or more meters long. Samples of this size and shape can give little information as to what types of distributions are present on a scale of ten to fifty meters. The only studies of distributions on a scale smaller than one hundred meters have been by Cassie (1959b), who sampled phytoplankton with glass jars spaced ten centimeters apart, and a recent study by Wiebe (1968), who used a Longhurst-Hardy sampler to study the distribution of zooplankton on a scale of about ten meters. Both these studies showed considerable patchiness of planktonic organisms on a small scale.

The purpose of this study was to sample the zooplankton of selected regions of Kaneohe Bay using a Longhurst-Hardy sampler and sampling on a scale of fifteen to forty-five meters. The results of this sampling program were used to determine what animals exhibited patchy distributions and to what extent correlation between species abundances was related to patchiness; and to compare the patterns of patchiness between the different regions.

STUDY AREA

Kaneohe Bay (Fig. 1) is located on the north-eastern coast of Oahu, Hawaii. It is an elongate oval shape with a surface area at mean sea level of 4.99×10^7 m^2. The maximum length of the Bay is 12.7 km, and the maximum width is 4.2 km. On the seaward (north-eastern) edge Kaneohe Bay is seperated from the open sea by a barrier reef.

Kaneohe Bay has been divided into several sectors on the basis of changes in the zooplankton and phytopkankton communities. The sectors, shown in Fig. 1, are : South Sector, Transition Zone, Middle Sector, North Sector, North Channel, and Sampan Channel. Previous investigators (Piyakarnchana, 1965, Peterson, 1968, Clutter, 1969) have shown differences in the zooplankton abundances and the concentrations of plant pigments in the different sectors. Clutter (1969) showed that the concentrations of Chlorophyll a and the numbers of phytoplankton, microplankton, and macroplankton all were highest in the Southern Sector, followed by the Transition Zone, Middle Sector, North Sector, North Channel and Sampan Channel in decreasing order. It was also shown that the mean numbers of meroplanktonic animals did not change significantly from place to place, while the mean numbers of holoplanktonic animals decreased from the Southern Sector northward to the North Channel, and were lowest in the Sampan Channel.

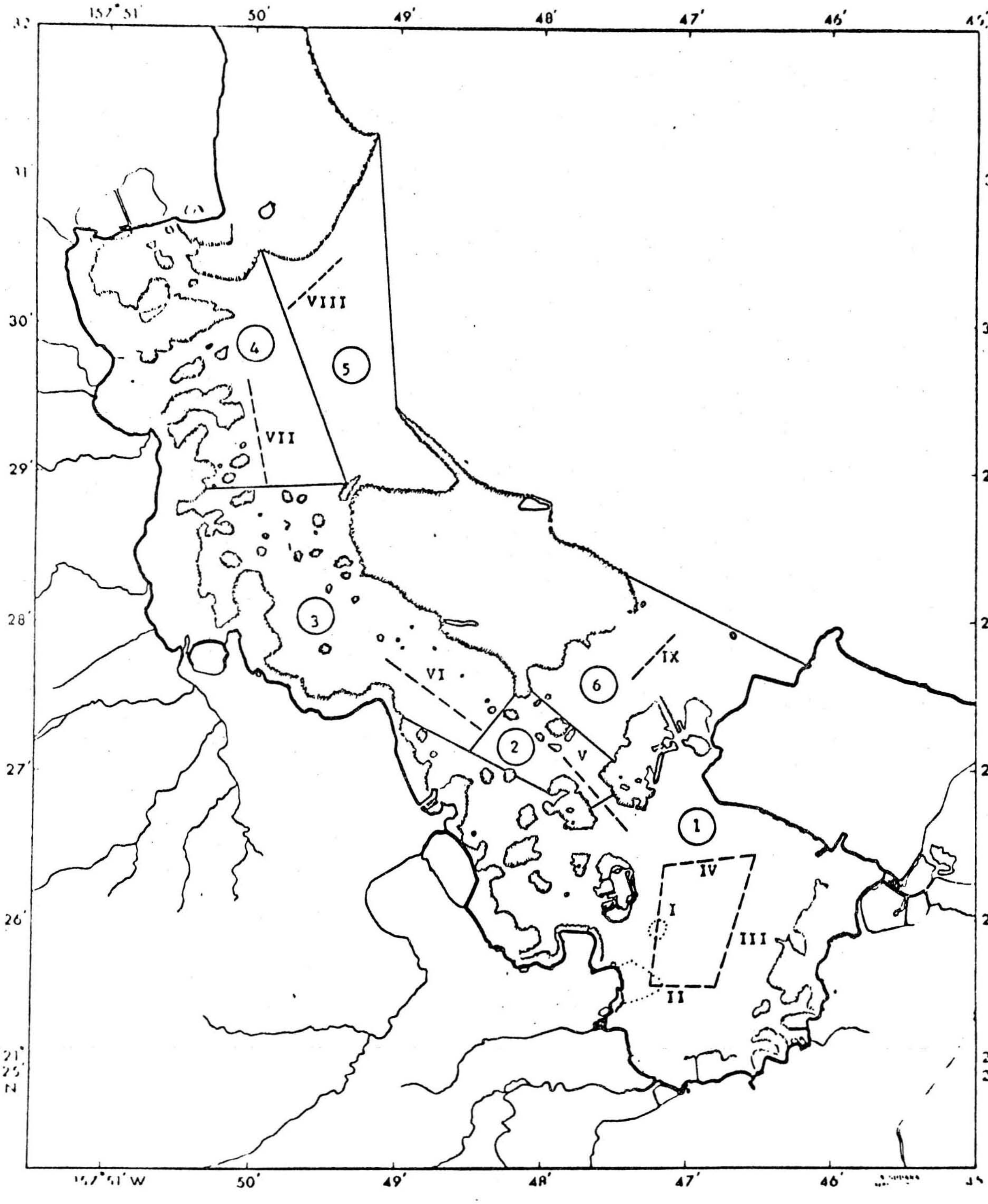

Fig. 1. Kaneohe Bay. The sectors of the Bay are (1) Southern Sector, (2) Transition Zone, (3) Middle Sector, (4) North Sector, (5) North Channel, (6) Sampan Channel. Tows are marked with Roman numerals.

MATERIALS AND METHODS

A modified version of the Longhurst-Hardy plankton sampling system (Longhurst et al, 1966) was used for this study. The main components of the system were a plankton recorder, an electronics case, and the net and frame (Fig. 2).

The plankton recorder utilized the Hardy (1936) principle of trapping the plankton caught by the net in a sandwich of gauze, but instead of advancing continuously, the system advanced in discrete jumps at the command of a timing circuit in the electronics package.

The electronics pressure housing contained a battery pack, timing circuit, and a Rustrak recorder which recorded event marks from the timing circuit and data from a flow meter. The flow meter was a standard Model 5 T. S. K. meter modified to send an event signal to the recorder for every thirty revolutions of the rotor. By towing the flow meter over a measured distance at several speeds, it was found that each event mark represented a distance of 5 meters at speeds from 50 to 150 cm./sec.

The net consisted of four sections of standard 330μ nylon plankton netting: three cylinders and a terminal cone. The cylinders were each 50 cm. in diameter and 80 cm. long. The cone was also 50 cm. in diameter at its larger end, and tapered to a cod end 10 cm. in diameter; the axial length of the cone was 140 cm. This combination of cylinders and cone gave a filtering area to mouth area ratio of 12.5 to 1. It has been shown (Smith et al, 1968) that a ratio of filtering area to mouth area of at least 10 to 1 is necessary if one is to sample at 85% efficiency in waters as productive as those of Kaneohe Bay for any length of time.

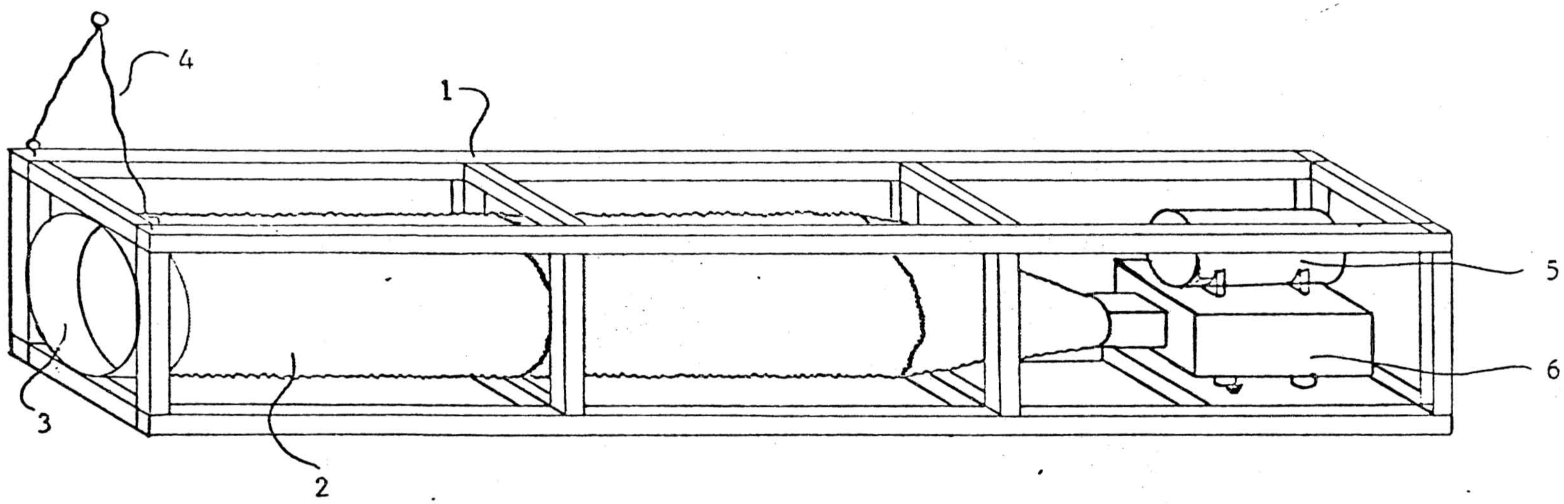

Fig. 2

The Longhurst-Hardy Plankton Sampler

1 Supporting Frame
2 Nets
3 Aluminum Collar
4 Bridle
5 Electronics Package
6 Plankton Collector

Since the tows of this study were to last at least ten minutes, it was necessary to maximize the net filtering area to mouth area ratio. In actual practice no clogging of the net was observed.

The frame to carry the different components was made of square cross-section aluminum tubing. The net was attached to an aluminum cylinder 50 cm. in diameter and 20 cm. long. The bridle was attached such that no wires or other material were in front of the net. These modifications were intended to reduce the avoidance of the nets by the zooplankton.

Samples were taken in each of the six sectors. Nine tows were taken with the device, four in the Southern Sector, and one in each of the other sectors (Fig. 1). Tows I-IV, forming a rough rectangle, were taken in the Southern Sector on March 4, 1969. Tow V was taken in the Transition Zone on June 19, 1969, and Tows VI-IX were taken in the remaining sectors on September 29, 1969. To minimize variations due to weather and vertical migrations, all tows were taken in the afternoon, with light (5-7 kt.) N.E. tradewinds, and partial cloud cover.

All tows were taken with the net sampling just below the surface, collecting the zooplankton from the upper 50 cm. The nets were towed at 100 to 150 cm./sec. For Tows I-IV, a sampling interval of 30 sec. was used, and for Tows V-IX the sampling interval was 10 sec. These were equivalent to distances of 45 and 15 meters, respectively. All tows were taken as nearly as possible along the central axis of the deeper channels and away from reefs. Table I gives the general data for the tows.

Table I. The date, time of tow, tide state, distance travelled, number of samples, total volume of water filtered and average volume filtered (volumes uncorrected for filtering efficiency) for each of the tows taken.

Tow #	Date (1969)	Time	Tide State	Distance travelled	Number of samples	Total volume (m^3)	Average volume (m^3)
I	3/4	1400	In	1470	30	290	9.6
II	3/4	1410	In	540	10	106	10.6
III	3/4	1420	In	1640	33	322	9.7
IV	3/4	1430	In	765	15	150	10.0
V	6/19	1330	Out	815	50	160	3.2
VI	9/29	1430	Out	1020	65	200	3.1
VII	9/29	1500	Out	920	50	180	3.6
VIII	9/29	1530	Out	835	48	163	3.4
IX	9/29	1400	Out	420	24	83	3.4

ANALYSIS OF DATA

After collection, the gauze strips were placed in a 5% formalin solution and preserved until counting. The samples were seperated from the gauze strips and counted under a dissecting microscope. All the animals in a sample were counted. The animals which occured in each region are given in Table II. The counts for the tows are given in Appendix I.

The data was analysed on an IBM 360/65 computer. First, the mean, standard deviation, and index of dispersion (Fisher, 1950) were calculatedfor the set of abundance data for each animal group found in each tow. The results of this computation are given in Appendix II. The indices of dispersion were tested for significant deviation from randomness. All but three of the sets of data were found to deviate significantly ($P = .05$) from randomness, all in the direction of overdispersion (patchiness). The other three did not deviate significantly from randomness.

Patches in a set of abundance data have been defined for this study as those samples which produced deviation from randomness when the set of data was tested for goodness of fit to a Poisson distribution. The remaining samples in a data set would then be those which did not deviate from aPoisson distribution. Inorder to find which samples were parst of patches each set of abundance data was first ranked in descending order of magnitude. The range of abundance, r, was calculated, and n equal sized classes of abundance were set up (n varying from 5 to 20, inclusive). The abundance data was then fit into these n classes, giving a frequency distribution. The mean of the frequency distribution was

Table II. The occurances of the animals caught in the different sectors. A " + " denotes the presence of the animal in that sector.

Animal	Southern Sector	Transition Zone	Middle Sector	Nortn Sector	North Channel	Sampan Channel
Lucifer chaeci	+	+	+	+	+	+
Sagitta enflata	+	+	+	+	+	+
Labidocera spp.	+	+	+	+	+	+
Zoea	+	+	+	+	+	+
Nauplii	+	+		+	+	+
Mysis		+	+	+	+	+
Alima	+		+	+		
Cypris	+					
Acartia hamata						+
Copilia spp.			+			

then calculated. This frequency distribution was then tested (K. S. Test, Tate and Clellan, 1951) for goodness of fit to a Poisson distribution calculated with the same mean and number of classes, n, as the observed distribution.

If the observed distribution did not deviate significantly (P = .05) from the corresponding Poisson distribution, the process stopped for that data set. If the observed distribution did deviate significantly from the corresponding Poisson distribution, the largest value in the set of abundances was removed, and the process was repeated. This continued until the observed distribution did not deviate significantly from the corresponding Poisson distribution. The samples which were removed were then said to have been patches or parts of patches. This proceedure for determining the patches in a set of abundance data is completely objective, reproducable, and consistant with a definition of patchiness which requires a departure from randomness. One can compare this with Wiebe (1968), who called all samples which were greater than the median value in a set of abundances patches, thereby assuring that all data showing any variation is patchy.

This analytical proceedure produced three types of results. The first were those distributions which did not deviate from randomness for all class sizes, without any samples being removed from the data set. The second type of distribution deviated from randomness, and had large ranges of abundance permitting division of the abundance data into 20 classes. For these, the number of samples picked out as patches increased as the number of classes used increased. The number of samples picked out for 20 classes was used in the further analyses. The third type of distribution showed deviation from randomness but had ranges of abundance that did not permit as many as 20 classes. Since the data were integer values, the number of classes that could be set up for these distributions was limited by the range of the data. The results of the computer analysis for locating patches are given in Table III. The plots of abundance vs. sample number for the sets of data which showed patches are given in Appendix III.

The sets of abundance data for each tow were also analysed for inter-specific correlations. The data for each tow were ranked in descending order of magnitude, and Spearman's rank correlation coefficient (Snedecor and Cochran, 1967) was calculated for all combinations of two animals. The results are given in Table IV.

Table III. The results of the computer analysis for patch location. A " - " indicates that the animal did not occur in that region. A " + " marks those sets of data which had no patches. Figures for the others are the number of patches (samples removed) / the maximum number of classes used.

Animal	Southern Sector	Transition Zone	Middle Sector	North Sector	North Channel	Sampan Channel
Lucifer chaeci	31/20	+	+	19/20	3/20	+
Sagitta enflata	+	+	+	+	+	+
Labidocera spp.	+	+	20/20	9/20	5/15	+
Alima	11/7	-	6/20	+	-	-
Zoea	16/20	+	10/20	6/20	+	+
Nauplii	22/20	+	-	+	+	+
Mysis	-	+	25/15	12/14	+	+
Cypris	26/15	-	-	-	-	-
Acartia hamata	-	-	-	-	-	+
Copilia spp.	-	-	5/10	-	-	-

Table IV. The Spearman rank correlation coefficients for all combinations of two animals. Non-significant correlations are marked with an " 0 ". Significant (P = .05) correlations are marked with an " + " or an " - ". Highly significant (P = .01) correlations are marked with an " (+) " ar an " (-) ".

	Tow #					
Animal pair	I-IV	V	VI	VII	VIII	IX
Lucifer-Sagitta	(+)	(+)	(+)	0	(+)	(+)
Lucifer-Labidocera	(+)	(+)	(+)	0	0	0
Lucifer-Zoea	(+)	0	(+)	0	+	0
Lucifer-nauplii	(+)	0		0	+	(+)
Lucifer-mysis		-	0	0	(+)	(+)
Lucifer-alima	(+)		(+)	0		
Lucifer-Copilia			+			
Lucifer-cypris	(+)					
Lucifer-Acartia						(+)
Sagitta-Labidocera	0	+	+	+	0	0
Sagitta-zoea	(+)	0	0	0	(+)	0
Sagitta-nauplii	(+)	0		0	0	0
Sagitta-mysis		0	(-)	0	0	0
Sagitta-alima	(+)		+	0		
Sagitta-Copilia			(+)			
Sagitta-cypris	(+)					
Sagitta-Acartia						0
Labidocera-zoea	0	(-)	(+)	0	0	(+)
Labidocera-nauplii	0	(+)		0	0	(+)
Labidocera-mysis		(-)	0	0	0	0
Labidocera-alima	0		(+)	0		
Labidocera-Copilia			0			
Labidocera-cypris	0					
Labidocera-Acartia						0
Zoea-nauplii	(+)	(-)		0	(+)	(+)
zoea-mysis		(+)	(+)	0	(+)	(+)
zoea-alima	(+)		(+)	0		
zoea-Copilia			(+)			
zoea-cypris	(+)					
zoea-Acartia						(+)
nauplii-mysis		(-)		0	+	(+)
nauplii-alima	(+)			0		
nauplii-cypris	(+)					
nauplii-Acartia						(+)
mysis-alima			0	-		
mysis-Copilia			(+)			
mysis-Acartia						(+)

RESULTS

POPULATION DENSITIES

Ten different animal groups were enumerated in this study. They were Lucifer chaeci, Sagitta enflata, Labidocera spp. (female), the alima larval form of several species of stomatopods,the zoea of several species of brachyuran crabs, the nauplii and cypris larval stages of barnacles, the mysis stages of various shrimp, mainly Cragnon, and the copepods Acartia hamata and Copilia spp. The mean values of abundance of the six most abundant animal groups are plotted by sector in Fig. 3. Lucifer and Sagitta were most abundant in the Transition Zone, and decreased in abundance toward the North Channel. Abundances of Lucifer and Sagitta were very low in the Sampan Channel. Labidocera was most abundant in the Middle Sector. Zoea and mysis were most abundant in the Transition Zone and Middle Sector. The nauplii were most abundant in the Southern Sector and low in abundance elsewhere. These results generally agree with Clutter (1969). Differences are probably due to differences in sampling method and seasonal changes in population densities.

PATCHINESS

Southern Sector

Of the seven animals found in the Southern Sector, only Sagitta and Labidocera had distributions which did not deviate from a Poisson distribution. The plots of abundance vs. sample number for the remaining animals are given in Appendix III, Figs. A.1 - A.5. The shaded areas in the plots indicate the areas determined to be patches. The patches generally occured in the same areas for all the animals: near sample

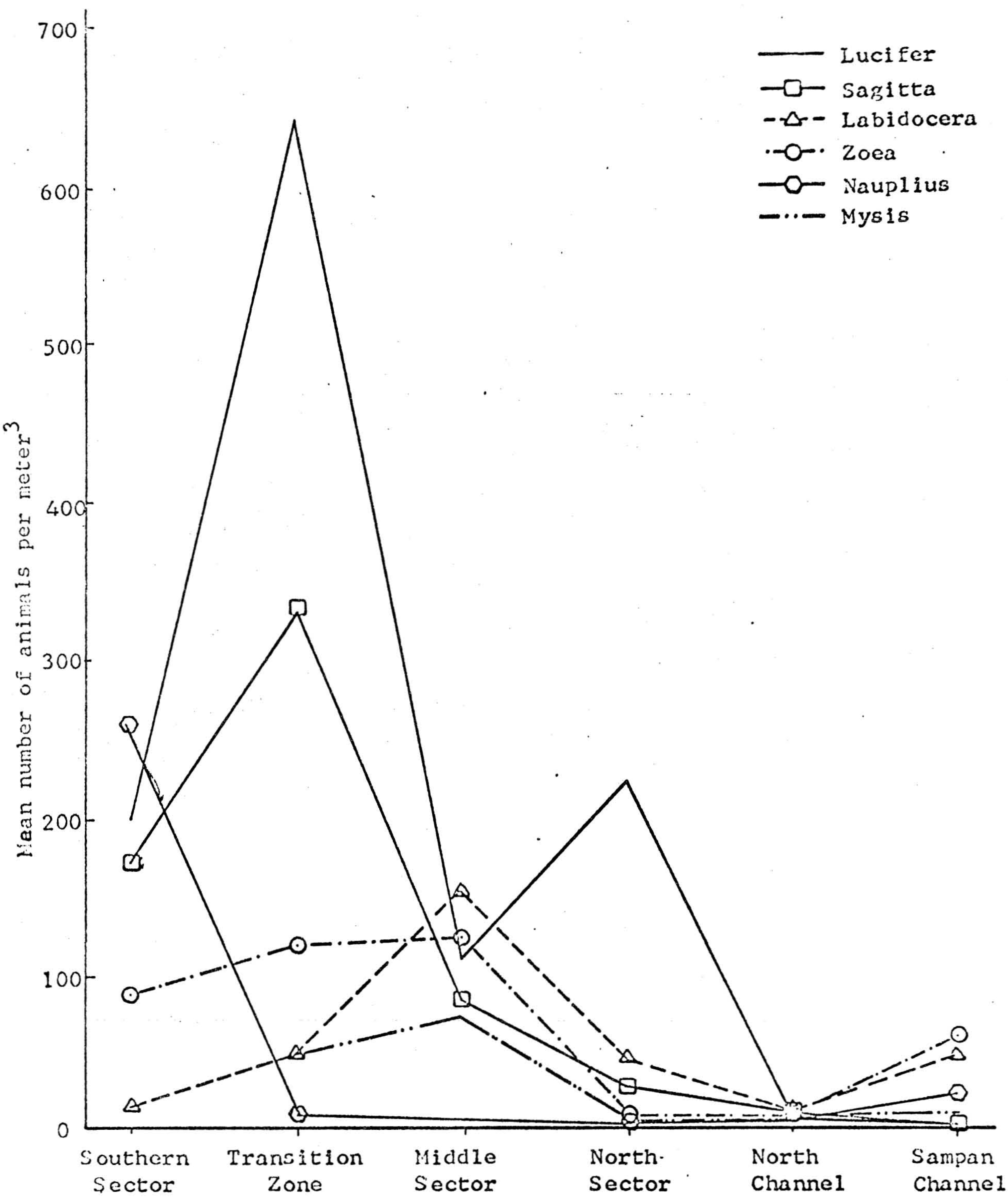

Fig. 3. The plot of mean abundance vs. sector for the six most abundant animals caught in this study.

numbers 10 - 15 and sample numbers 30 - 40 or 48. Fig. 4 shows an enlarged view of the Southern Sector and the path followed during the sampling. A small patch reef was crossed at samples 10 - 14. The area from Buoy II to Buoy III and slightly beyond was covered by samples 30 - 48.

The distribution of Lucifer showed a large patch from between Buoys IV and I all the way to mid-way between the patch reef and the fringing reef. The greatest abundance was just over the patch reef. Two smaller patches occured in the region of Buoys II - III.

The distributions of alima, nauplius cypris and zoea were all nearly identical; all showed a small patch over the patch reef (although the population density in the patch of zoea is not high enough to be statistically significant). All had much greater population densities in the region of Buoys II - III, the greatest densities occuring around sample number 33, which was just beyond the edge of the fringing reef and over deep water.

Transition Zone

All of the animals found in the Transition Zone werefound not to deviate from randomness. Labidocera, zoea, nauplii, and mysis showed gradients in their abundances. Zoea and mysis had gradients increasing to the north, while Labidocera and nauplii had gradients decreasing to the north. The values of the gradients (the slope of the linear regression equation of abundance vs. distance) were: zoea - 4.5 animals per 15 meters; mysis - 1.6 animals per 15 meters; Labidocera - 1.7 animals per 15 meters; nauplii - 0.5 animals per 15 meters.

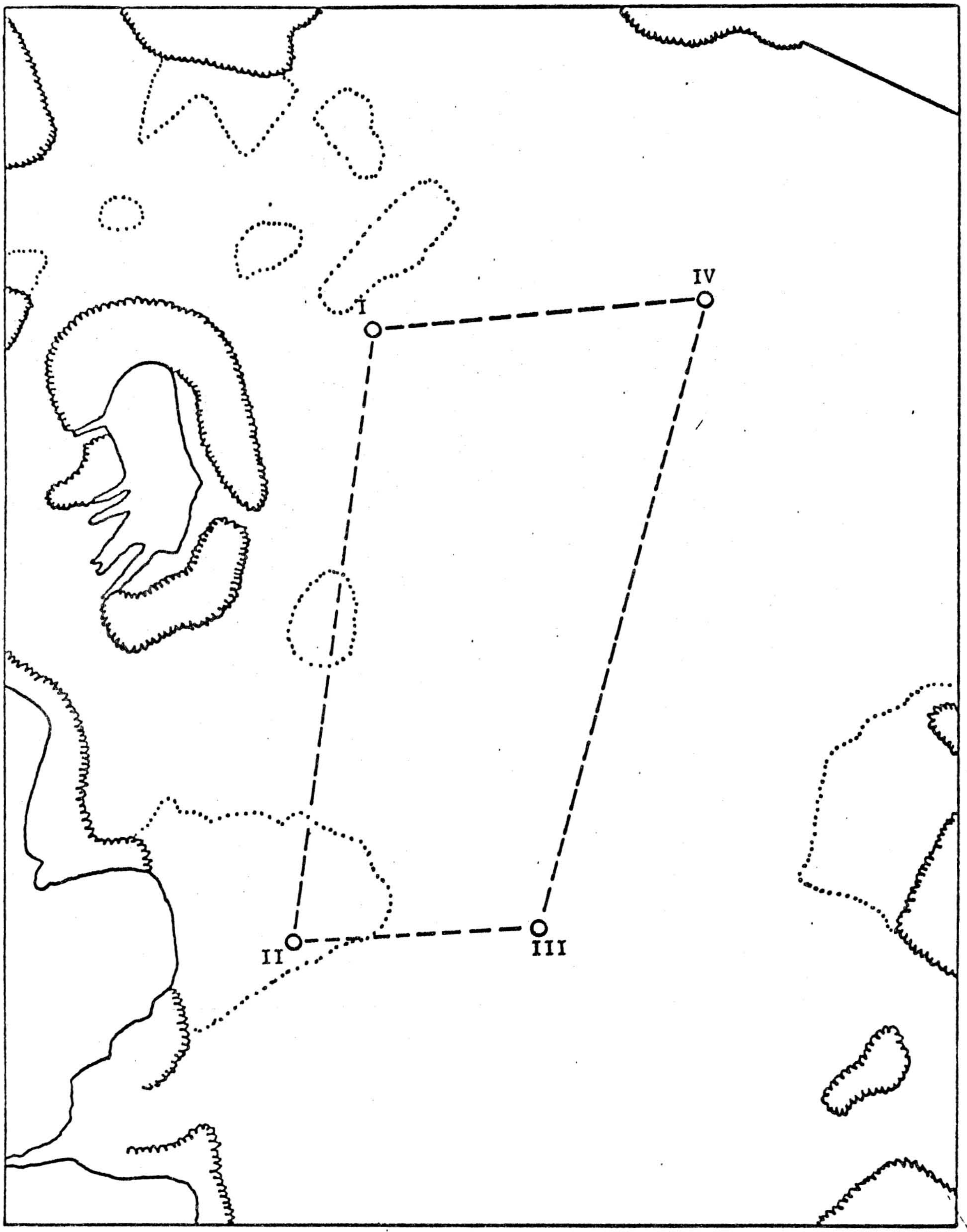

Fig. 4. The Southern Sector of Kaneohe Bay, with the path taken on the sampling tows, and showing the location of the four marker buoys.

Middle Sector

The distributions of Lucifer and Sagitta in the Middle Sector did not deviate from a Poisson distribution. Sagitta showed a gradient of 2.3 animals per 15 meters increasing to the north. Lucifer showed no gradient. The remaining five animals had patchy distributions, and no gradients. The patches are shown in the plots of abundance vs. sample number for these five animals given in Appendix III, Figs. A.6 - A.10. All five animals had patches in their distributions at the beginning of the tow. There were also patches of Labidocera, mysis, zoea and alima near the middle of the tow, and Labidocera and alima had patches at the end of the tow.

North Sector

Of the seven animals found in the North Sector, four (Lucifer, Labidocera, zoea, and mysis) had patchy distributions. The plots of abundance vs. sample number (given in Appendix III, Figs. A.11 - A.12) show little common pattern in the location of the patches. All the animals had patches at the beginning of the tow, but they are of different relative size.

North Channel

Two of the animals found in the North Channel had patchy distributions. Patches of Lucifer occured in 3 samples out of 48, and patches of Labidocera occured in 5 samples. The distributions of the remaining animals did not deviate from a Poisson distribution.

Sampan Channel

The distributions of all the animals found in the Sampan Channel were found not to deviate from a Poisson distribution.

Correlation Coefficients

In the Southern Sector, the two animals whose distributions did not deviate from a Poisson distribution (Labidocera and Sagitta) were not significantly correlated with each other. The other five animals, whose distributions were quite simular, showed highly significant positive correlations. Sagitta showed positive correlations with some of the patchily distributed animals, but Labidocera did not.

In the Transition Zone, the distributions of all the animals did not deviate from randomness. The animals which showed gradients in their distributions showed significant correlations. Labidocera and nauplii, which had gradients in one direction, were positively correlated, as were zoes and mysis, which had gradients in the other direction. The correlations between animals with gradients in different directions were negative and highly significant. Lucifer and Sagitta, the two animals which did not exhibit gradients in their distributions, were positively correlated. They were both positively correlated with Labidocera.

In the Middle Sector, Lucifer and Sagitta did not deviate from randomness. Sagitta had a gradient in its distribution, and Lucifer did not. The correlation coefficients for those animals showing patchy distributions were generally positive and significant. The correlation coefficients for Sagitta with mysis and Copilia were negative and highly significant. Lucifer was highly significantly positively correlated with most of the other animals.

In the North Sector the only significant correlation coefficients were between Sagitta and Labidocera (positive) and between mysis and alima (negative). Sagitta and alima did not deviate from randomness, while Labidocera and mysis were patchy.

In the North Channel and in the Sampan Channel, the animals whose distributions were patchy were not significantly correlated, while animals whose distributions did not deviate from randimness in most cases had highly significant correlations (positive) with each other.

DISCUSSION

The pattern of the variations in abundances of the animals found in this study agree with those found by Piyakarnchana (1965), Peterson (1968), and Clutter (1969). The greatest abundance of animals was found in the Southern Sector or the Transition Zone where the standing crop of phytoplankton is the greatest. The high standing crop is generally attributed to the increased nutrient concentration due to run-off and the influx of treated sewage and to the restricted pattern of circulation in the Southern Sector. The standing crop of phytoplankton decreases in hte rest of the Bay, being lowest in the North Channel and the Sampan Channel. The decrease is due to some combination of decreased nutrient concentration due to utilization by phytoplankton and mixing of water masses, and grazing by herbiverous zooplankton and fish. The abundance of the zooplankton appears directly related to the phytoplankton concentration.

The data from the Southern Sector indicated that Lucifer and the meroplankton in the region were associated with two bathymetric features or benthic communities. The distributions of alima, nauplii, cypris and zoea all showed definite patches, i. e. higher population densities, associated with a patch reef and with a somewhat isolated cove.

The association of these planktonic animals with the patch reef could be either passive or active. If passive, this would mean that the currents around the patch reef were such that the animals were not carried away. Bathen (1968) suggests that the currents in this area cross the reef without forming a gyre, and also change direction with the tides. It would seem unlikely that the association of these animals with the patch reef is purely a passive one and the result of physical forces.

The patch reef is a unique feature in the Southern Sector of Kaneohe Bay. The reef top (three meters deep) was covered with benthic algae, living and dead corals, and patches of sand. There were barnacles living on nearly all the exposed areas of the dead coral and coral rubble. The sandy areas were inhabited by both crabs and stomatopods. The area surrounding the patch reef had a mud-silt bottom about thirteen meters deep. There were no barnacles there, and crabs and stomatopods were almost certainly less abundant.

Possibly these animals were spawned on the patch reef and by some means of position location stayed above or very near the patch reef. They could also have been spawned elsewhere, drifted aimlessly with the currents until they passed over the patch reef, and then stayed there.

Light readings using an underwater light meter were taken just below the surface over the patch reef and over the surrounding areas. The upwelling light was five times greater over the patch reef than over the deeper surrounding areas.

All of the larval animals have well developed light-sensing organs, and all could discriminate and associate with this lighter background during the day. Several of these animals were collected using a night-light and were placed in a large outdoor sea-water tank. The bottom of the tank was covered with black plastic with several light patches on it. The animals aggergated over these light patches almost immediately. It is possible that the animals used the light background as a reference point during the day, and migrated down to close physical proximity with the patch reef during the night. None of the studies done previously in Kaneohe Bay have shown any evidence for inverse diurnal vertical migration in these animals.

Another possibility for the aggregation of the animals over the patch reef is that food may be more abundant there. The animals are likely either herbivores or feed on the microcopepods. Recent studies by myself using a flurometer showed a definite decrease in plant pigment concentration in the water over the patch reef. It is not known whether this decrease in plant pigment concentration was the result of grazing by this resident population of herbivores, or grazing by the microcopepods, upon which the carnivores feed.

The area of the second major patch in the distribution of these four animals was in an area where data from Bathen (1968) suggested a tendency for the currents to form a clockwise gyre. Such a mechanism could hold animals spawned in the area if they lacked a preferred position such as was found over the patch reef.

No difference in upwelling light was found in the area of the patch and the surrounding areas. The pigment sampling showed definite increases in the concentration of plant pigment in the area of the patch, which was very near a sewage outfall. Possibly a greater food supply partially accounts for the greater population densities found in this area.

The distributions of the other animals caught in the Southern Sector and of those caught in the other sectors of Kaneohe Bay showed no such relationships with bathymetric features. Their distributions, and the departures from randomness that were found, would seem to be controlled by passive movement by turbulence set up by the mixing of different water masses, by active reaction to gradients in the environment such as temperature, salinity, or food concentration, by biological factors such as feeding, mating, or spawning, or by some combination of the three.

No measures of the physical parameters of the water of the different areas were made during the sampling. Bathen (1968) indicates that the gradients in temperature and salinity are greatest in the Transition Zone and the Middle Sector, less through the North Sector, North Channel and Sampan Channel, and least in the Southern Sector. Small-scale heterogeneity of water characters set up by the mixing of two different water masses is probably greatest in the Transition Zone and the Middle Sector, where water from outside the Bay mixes with the Bay water. Also, small-scale heterogeneity could be expected, but to a lesser extent, in the North Channel and the Sampan Channel, where water enters the Bay.

The effect of the currents and mixing on the distributions of hte animals must be of some importance. The Spearman rank correlations given in Table IV show that in many cases animals whose distributions did not deviate from randomness were significantly correlated. This would suggest that although the distributions of the animals fit a Poisson distribution, there was a significant co-occurance of high and low values of abundance. The co-occurance of high and low values of abundanee (or in the case of negative correlations, high with low and low with high values) could be the result of the mixing of two water masses which had different mean population densities. If the mixing of these water masses was incomplete, areas of relatively high or low densities of animals would result. Sampling in a line across this incompletely mixed area would result in the co-occurance of high and low population densities.

The gradients in the distributions of the animals occured in the

Transition Zone and the Middle Sector. A gradient in the distribution of an animal would most likely be due to a process of spreading out from a center of high population density into areas of low density, much like the diffusion of a gas, or could be the result of very thorough mixing by turbulence on a scale smaller than that sampled by the sampler. In the Transition Zone and the Middle Sector one would expect the mixing to be greatest. The fact that the animals in the Transition Zone had gradients in their distributions, and that their distributions did not deviate from randomness, suggests that the effect of mixing is greatest in the Transition Zone, and that it is complete enough to result in the random distribution of the animals.

CONCLUSION

Two general types of patchiness were found in the distributions of some of the zooplankton in Kaneohe Bay. Large scale patches were found associated with bathymetric features. Alima, nauplii, cypris, and zoea, all larval forms, were found to be associated quite closely with an isolated patch reef and a relatively isolated embayment. The mechanism of the associations with these two features are probably different. In the case of the patch reef, where current patterns would not tend to keep the animals in the area, the mechanism is probably an active association with a background of lighter color during the day, and a close physical association with the isolated bathymetric feature during the night. It has been observed in the laboratory that these larval forms do tend to associate with light areas in a dark background, and it has been observed that some plankters do associate with bathymetric features (Emery, 1968).

The mechanism of the association of these larval forms with the relatively isolated embayment is probably different than that for the patch reef. In the embayment there is no difference in background light, and the animals have no feature with which they can actively associate. In this case, they probably exhibit a random swimming movement, and the pattern of water movement can have a greater effect on their pattern of distribution. In this area the currents tend to form a gyre which is relatively closed, and which would tend to keep most of the animals in one location.

The second type of patchiness, on a smaller scale, was that shown in the other regions of Kaneohe Bay. The patches did not show any relation to bathymetric features, and there are no currents forming large-scale gyres. The probable mechanism affecting the distribution of the zooplankton may be the turbulent mixing of different water masses. Some of the animals whose distributions did not deviate from randomness were significantly correlated with other non-deviating animals, or with animals whose distributions were patchy. The turbulent mixing of two water masses with different population densities could result in areas of high and low population densities for several animals occuring in the same place. This would seem to be what was occuring in the parts of Kaneohe Bay outside the Southern Sector.

APPENDIX I

Summary of the counts of animals for Tows I-IX

Data for Southern Sector are (animals / $9m^3$)

Data for remaining regions are (animals / $3m^3$)

Southern Sector

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ZOEA	ALIMA	NAUPLIUS	CYPRIS
1	113	113	2	45	0	55	3
2	241	137	22	70	6	79	5
3	146	140	42	46	1	62	3
4	400	189	18	74	0	72	7
5	231	173	53	76	5	57	8
6	368	126	24	81	3	83	4
7	227	118	9	57	3	44	6
8	369	163	7	76	3	102	2
9	447	139	12	68	6	100	5
10	392	78	17	45	11	70	4
11	859	86	20	40	17	193	23
12	864	219	25	29	14	367	142
13	463	181	9	16	3	309	115
14	518	260	10	18	1	304	115
15	319	223	5	47	3	595	183
16	267	225	2	127	3	502	203
17	186	218	3	98	3	212	32
18	189	271	3	77	3	232	32
19	118	202	1	56	2	183	24
20	70	173	0	36	1	107	13
21	70	123	0	28	0	83	5
22	53	110	3	26	0	69	2
23	66	87	3	26	1	49	5
24	55	62	1	42	1	52	4
25	54	79	7	40	2	46	8
26	64	86	9	44	2	33	4
27	46	81	11	55	2	59	6
28	62	100	14	47	2	80	2
29	41	114	3	46	0	261	8
30	67	101	7	85	3	268	11
31	243	183	2	275	13	728	116
32	425	467	1	613	15	2654	316
33	256	340	3	504	8	2064	273
34	264	268	2	495	15	1364	421
35	160	271	2	461	11	959	147
36	180	225	1	302	12	555	55
37	145	150	3	122	10	680	42
38	369	266	11	212	21	1678	70
39	299	173	13	117	7	934	38
40	301	146	13	125	7	739	44
41	144	327	17	143	2	145	26
42	107	221	7	123	2	124	31
43	153	197	24	148	1	176	51
44	105	149	13	163	1	1018	78
45	124	156	24	140	0	528	71
46	122	169	26	129	0	384	73
47	155	188	20	162	1	285	25
48	87	138	15	110	0	122	11
49	44	100	13	65	1	63	5

Southern Sector (cont.)

Sample No.	LUCIFER	SAGITTA	LABIDOCERA	ZOEA	ALIMA	NAUPLIUS	CYPRIS
50	14	53	3	32	0	22	5
51	12	65	11	34	0	36	3
52	13	99	12	25	0	19	3
53	35	246	24	71	0	44	6
54	24	151	15	41	0	41	3
55	11	96	13	26	0	19	3
56	21	131	13	44	0	44	1
57	15	107	14	34	0	16	0
58	26	202	14	46	0	25	1
59	60	312	14	66	0	40	3
60	72	345	19	56	0	47	3
61	77	245	15	45	0	40	3
62	102	212	10	36	0	26	0
63	83	130	10	26	0	24	0
64	119	153	20	32	1	32	3
65	94	125	9	25	1	19	3
66	52	76	13	9	1	19	2
67	13	34	1	6	1	17	0
68	32	35	6	11	0	21	3
69	65	23	1	7	1	13	6
70	8	5	3	1	0	4	0
71	15	19	2	5	0	3	0
72	63	48	20	15	0	23	0
73	122	67	19	15	0	36	2
74	110	72	23	10	0	28	2
75	223	190	37	25	2	53	2
76	263	199	30	25	1	54	6
77	341	270	26	51	0	59	2
78	363	269	38	37	2	40	3
79	295	181	19	13	1	56	1
80	341	243	24	41	1	46	6
81	381	281	35	49	3	48	1
82	459	251	37	39	2	54	6
83	473	255	25	43	2	57	8
84	542	309	31	75	2	45	6

TRANSITION ZONE

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ZOEA	NAUPLIUS	MYSIS
1	937	216	70	40	4	27
2	1043	223	79	44	11	22
3	816	315	56	44	16	29
4	844	303	70	57	14	26
5	920	324	123	42	34	31
6	795	336	176	46	24	23
7	579	300	142	25	18	17
8	909	390	138	58	42	32
9	284	191	75	28	15	15
10	343	317	98	41	12	27
11	480	363	104	58	38	26
12	353	495	49	61	33	43
13	568	379	43	65	25	35
14	766	366	22	47	20	32
15	548	288	33	46	13	19
16	435	243	82	12	14	
17	631	327	32	69	16	29
18	844	329	41	78	10	23
19	566	290	29	45	7	15
20	546	200	17	37	3	27
21	832	396	30	57	7	29
22	1081	371	45	69	11	28
23	659	283	40	68	2	26
24	652	304	36	65	4	29
25	1190	518	58	128	4	50
26	1023	488	53	114	5	43
27	704	342	59	88	4	39
28	807	330	45	87	1	34
29	685	346	45	104	3	35
30	655	477	50	138	7	55
31	637	425	22	109	5	39
32	674	387	29	151	6	64
33	627	346	31	166	4	68
34	916	395	31	228	2	63
35	455	428	30	180	1	59
36	569	402	51	175	3	68
37	650	435	52	185	1	47
38	683	387	37	181	3	68
39	628	356	37	189	0	48
40	563	372	28	178	1	63
41	567	338	31	157	0	85
42	438	264	41	163	1	73
43	333	228	18	144	2	53
44	350	198	17	133	2	55
45	327	217	8	162	5	65
46	284	238	13	278	2	57
47	189	166	6	98	4	70

TRANSITION ZONE (cont.)

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ZOEA	NAUPLIUS	MYSIS
48	336	187	7	237	7	130
49	296	210	12	353	9	177
50	227	204	15	302	10	154

MIDDLE SECTOR

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ALIMA	ZOEA	MYSIS	COPILIA
1	337	36	105	15	177	227	21
2	280	27	163	13	183	153	31
3	258	20	260	19	263	70	37
4	178	28	275	13	207	75	24
5	302	44	416	31	386	251	50
6	393	81	341	49	545	324	41
7	114	18	66	14	141	201	4
8	71	18	66	32	103	216	7
9	198	53	161	32	283	171	12
10	166	37	150	10	223	109	5
11	68	21	81	9	64	62	10
12	24	8	61	3	56	15	3
13	24	13	69	3	52	30	4
14	19	15	41	5	29	21	3
15	20	10	44	0	28	15	1
16	17	14	57	3	52	45	2
17	17	18	58	4	25	35	1
18	14	47	238	16	182	169	6
19	117	40	305	33	257	225	9
20	132	14	64	9	91	95	3
21	43	44	100	7	109	101	8
22	73	64	101	11	137	105	5
23	104	32	76	10	92	96	8
24	34	51	68	9	62	117	1
25	44	42	90	12	83	147	4
26	53	60	75	7	56	101	4
27	51	56	87	9	70	99	9
28	42	55	104	6	129	113	5
29	69	70	149	5	84	79	5
30	89	58	91	9	84	63	1
31	48	67	144	16	88	64	3
32	76	68	132	5	133	59	0
33	64	85	103	11	101	56	1
34	102	96	108	7	94	38	0
35	97	98	106	11	93	32	4
36	94	82	101	8	99	20	1
37	91	69	73	4	56	35	4
38	63	64	104	9	106	23	5
39	84	99	69	7	97	30	1
40	109	100	77	8	67	23	4
41	114	107	70	5	96	24	2
42	83	118	66	14	81	25	3
43	114	89	77	7	89	39	3
44	96	119	32	9	53	49	0
45	81	130	77	8	79	22	0
46	151	73	39	0	39	38	0
47	88	96	66	4	46	64	1
48	98	127	75	11	61	23	4

MIDDLE SECTOR (cont.)

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ALIMA	ZOEA	MYSIS	COPILIA
49	110	130	81	18	82	39	2
50	63	99	69	5	49	27	1
51	68	211	65	9	54	31	0
52	99	300	128	14	65	45	1
53	92	245	153	11	91	35	3
54	115	198	191	19	65	26	2
55	82	115	239	9	69	15	1
56	93	98	223	15	54	10	2
57	117	109	232	16	82	14	2
58	123	131	201	29	89	14	2
59	130	172	254	22	136	19	1
60	211	176	391	28	175	22	5
61	113	87	724	24	140	15	1
62	135	118	519	29	139	14	1
63	113	85	352	20	147	19	2
64	137	106	257	35	163	17	1
65	97	96	188	25	139	14	2

NORTH SECTOR

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ZOEA	MYSIS	NAUPLIUS	ALIMA
1	150	55	143	41	21	1	0
2	450	89	79	33	9	4	1
3	498	49	75	26	12	2	1
4	418	40	64	27	10	3	0
5	231	35	49	12	8	1	0
6	519	56	87	27	14	2	0
7	263	16	84	14	7	0	0
8	371	23	62	24	14	1	2
9	282	40	79	29	23	0	0
10	340	20	53	20	16	1	0
11	271	15	54	16	9	0	0
12	278	23	38	11	9	0	0
13	206	25	50	11	3	0	0
14	229	17	83	11	7	2	0
15	277	25	103	24	11	0	0
16	130	29	53	9	4	0	0
17	121	33	29	15	3	0	0
18	225	39	32	14	13	0	0
19	108	38	29	9	18	0	1
20	46	23	18	11	20	0	0
21	89	22	20	11	22	0	0
22	54	26	11	9	23	0	0
23	167	29	15	20	22	1	1
24	40	13	4	9	20	0	0
25	54	26	19	18	23	0	1
26	76	28	34	9	19	0	0
27	407	41	139	12	16	0	0
28	321	18	92	5	6	3	0
29	171	8	29	1	1	0	0
30	342	20	42	5	1	0	0
31	645	31	34	8	7	1	1
32	341	30	28	5	5	1	0
33	302	18	24	4	5	0	0
34	270	29	15	7	3	1	0
35	179	31	16	6	5	2	0
36	52	16	8	1	1	0	0
37	237	22	41	12	5	2	0
38	104	10	26	6	2	1	0
39	145	10	16	1	4	1	0
40	93	20	14	6	1	1	0
41	324	21	15	11	3	2	0
42	158	19	9	7	4	0	0
43	90	12	20	4	2	0	0
44	39	7	20	1	2	1	0
45	225	20	14	5	8	1	0
46	232	12	33	2	6	1	1
47	59	7	29	1	10	0	0
48	59	15	31	5	9	1	0
49	63	13	21	1	3	1	0
50	65	21	28	7	5	1	0

NORTH CHANNEL

SAMPLE No.	LUCIFER	SAGITTA	LABIDOCERA	ZOEA	NAUPLIUS	MYSIS
1	6	4	0	3	1	2
2	6	5	4	2	0	9
3	3	3	5	2	0	4
4	2	4	2	1	0	3
5	6	1	2	0	0	3
6	14	5	10	6	1	9
7	1	1	2	0	0	2
8	1	5	3	0	0	1
9	1	6	4	2	0	2
10	3	17	16	0	0	2
11	11	18	6	0	0	6
12	4	10	12	2	0	4
13	9	10	14	7	1	4
14	0	3	6	0	0	2
15	0	4	17	1	1	2
16	1	0	10	0	0	1
17	1	7	10	0	0	1
18	0	5	3	0	0	0
19	0	1	6	2	0	2
20	2	5	14	0	0	2
21	22	34	18	5	1	5
22	2	6	23	0	0	0
23	1	2	15	0	0	1
24	1	4	6	0	0	2
25	0	5	8	0	0	2
26	0	1	5	0	0	0
27	2	6	12	0	0	1
28	5	20	16	1	0	4
29	1	4	6	0	0	1
30	3	3	4	0	0	1
31	1	8	6	1	1	2
32	1	7	5	1	0	3
33	3	5	0	0	0	0
34	0	7	1	2	0	0
35	0	5	1	0	0	0
36	4	5	2	0	0	0
37	3	8	4	1	0	2
38	2	14	5	1	0	0
39	1	10	3	2	0	0
40	6	9	5	1	1	3
41	3	24	3	3	0	1
42	0	10	1	0	0	2
43	1	4	1	0	0	2
44	0	8	3	1	0	6
45	0	3	2	1	0	0
46	0	2	3	0	0	2
47	4	11	1	2	0	3
48	2	4	0	0	0	3

SAMPAN CHANNEL

SAMPLE No.	LUCUFER	SAGITTA	LABIDOCERA	ZOEA	NAUPLIUS	ACARTIA	MYSIS
1	11	1	57	140	82	134	13
2	6	0	48	83	52	82	4
3	9	4	42	48	41	65	5
4	6	0	45	38	24	32	4
5	1	1	20	18	6	18	0
6	6	1	36	21	17	34	2
7	5	0	39	37	36	46	2
8	2	6	38	39	15	32	6
9	3	0	8	17	4	17	1
10	8	0	10	51	13	47	2
11	6	0	15	67	16	59	7
12	0	0	10	19	3	21	2
13	0	2	19	49	11	31	3
14	8	0	50	115	37	86	12
15	2	2	31	65	25	30	5
16	1	2	85	125	36	74	10
17	2	3	42	71	17	49	4
18	0	0	47	71	29	30	3
19	1	0	100	84	37	44	2
20	0	0	132	82	28	35	5
21	0	0	78	78	17	23	3
22	0	0	41	14	2	4	1
23	0	0	15	3	1	2	1
24	0	0	6	0	0	0	0

APPENDIX II

Summary of statistics on the populations of Tows I-IX

LUCIFER

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV	192.1	178.7	166.3
V	633.3	236.4	88.3
VI	107.3	74.0	51.1
VII	217.0	143.9	95.4
VIII	2.9	4.1	3.7
IX	3.2	3.5	5.8

SAGITTA

TOW	MEAN	STANDARD DEVUATION	INDEX
I-IV	166.8	87.6	46.0
V	322.6	84.6	22.2
VI	80.8	57.8	41.3
VII	25.7	14.7	8.4
VIII	7.3	6.9	6.5
IX	0.9	1.6	2.6

LABIDOCERA

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV	13.9	11.3	9.2
V	48.2	36.3	27.3
VI	149.0	125.6	105.1
VII	42.0	32.3	24.8
VIII	6.4	5.6	4.9
IX	42.3	31.0	22.7

ZOEA

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV	85.1	112.6	149.0
V	112.6	77.6	52.8
VI	114.5	85.9	64.5
VII	11.7	9.2	7.2
VIII	1.0	1.5	2.3
IX	53.9	37.5	26.0

NAUPLII

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV	251.2	546.9	831.2
V	9.7	10.2	10.6
VI			
VII	0.8	0.9	1.2*
VIII	0.2	0.4	0.9*
IX	22.8	19.1	16.0

MYSIS

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV			
V	47.7	32.8	22.6
VI	70.4	69.1	67.8
VII	9.5	7.0	5.2
VIII	2.4	2.1	1.9
IX	3.6	3.3	3.0

ALIMA

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV	3.2	5.0	7.8
V			
VI	13.4	9.8	7.2
VII	0.8	0.5	1.0*

CYPRIS

TOW	MEAN	STANDARD DEVIATION	INDEX
I-IV	35.3	73.0	150.3

COPILIA

TOW	MEAN	STANDARD DEVIATION	INDEX
VI	5.9	9.8	16.2

ACARTIA

TOW	MEAN	STANDARD DEVIATION	INDEX
IX	41.3	30.5	3.0

An " * " following an Index value indicates that that distribution does not deviate significantly from a Poisson distribution (P = .05).

APPENDIX III

The plots of abundance vs. sample number

for those animals whose distributions were found to be patchy.

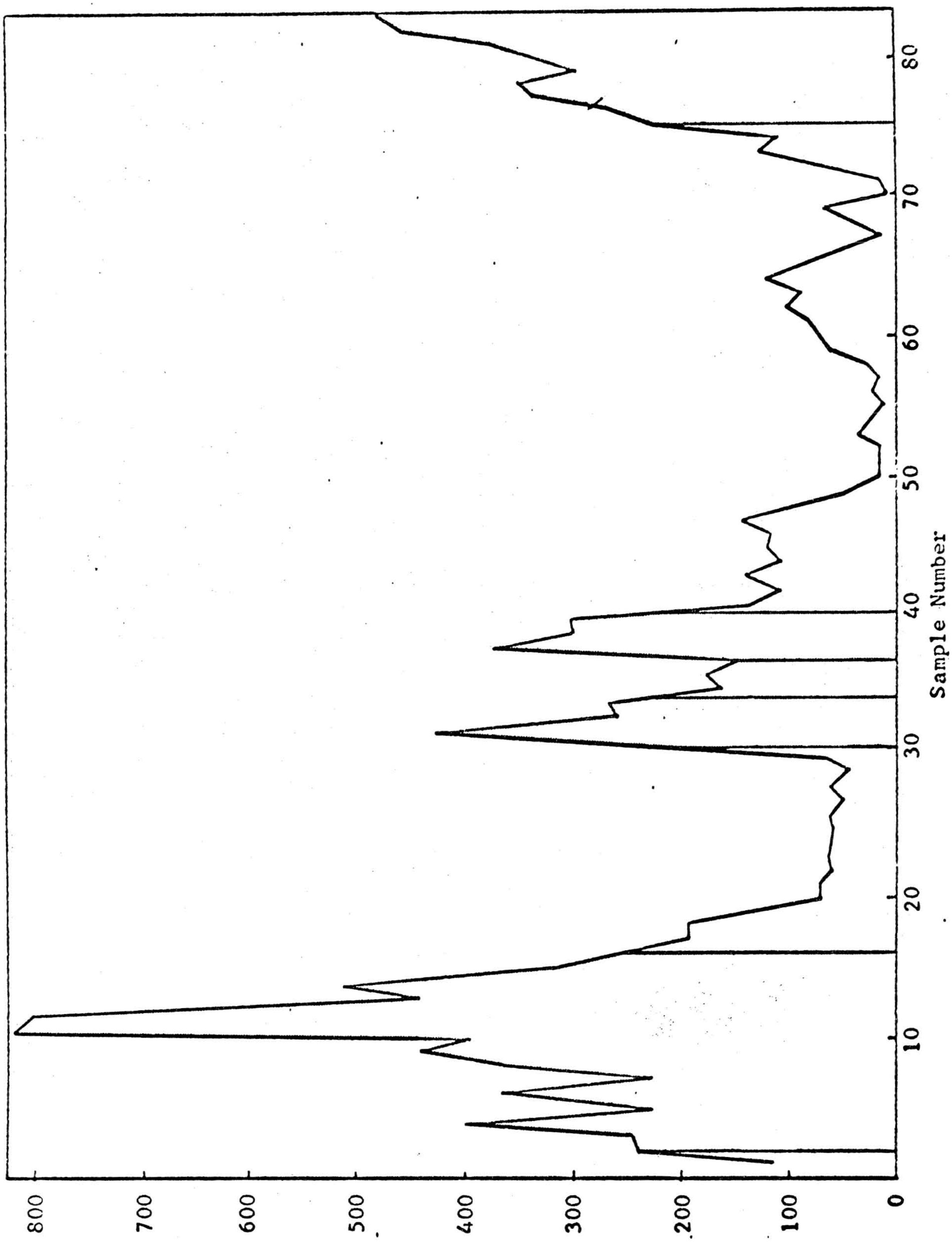

Fig. A.1. The plot of abundance (animals / $9m^3$) vs. sample number for Lucifer in the Southern Sector.

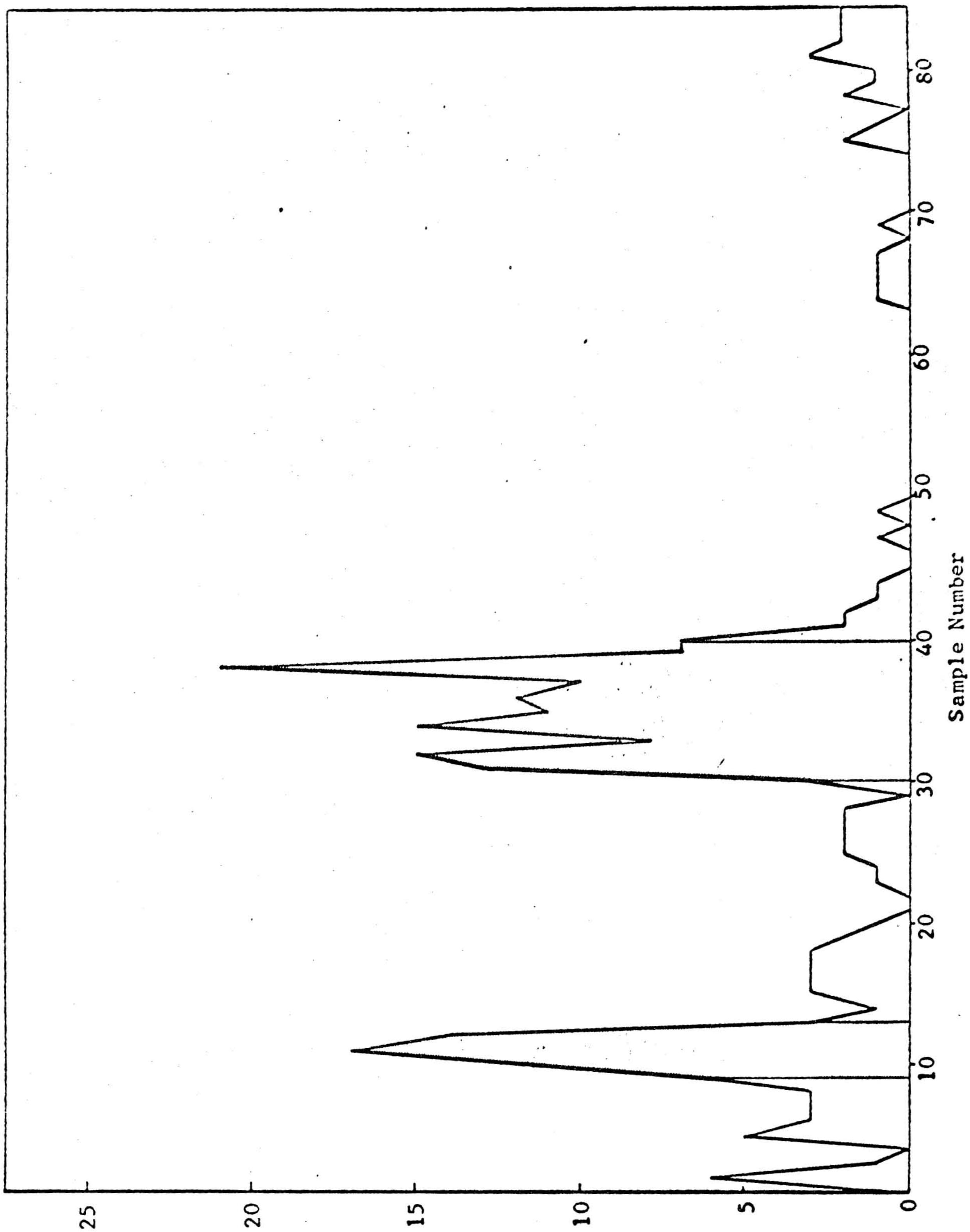

Fig. A.2. The plot of abumdance (animals / $9m^3$) vs. sample number for alima in the Southern Sector.

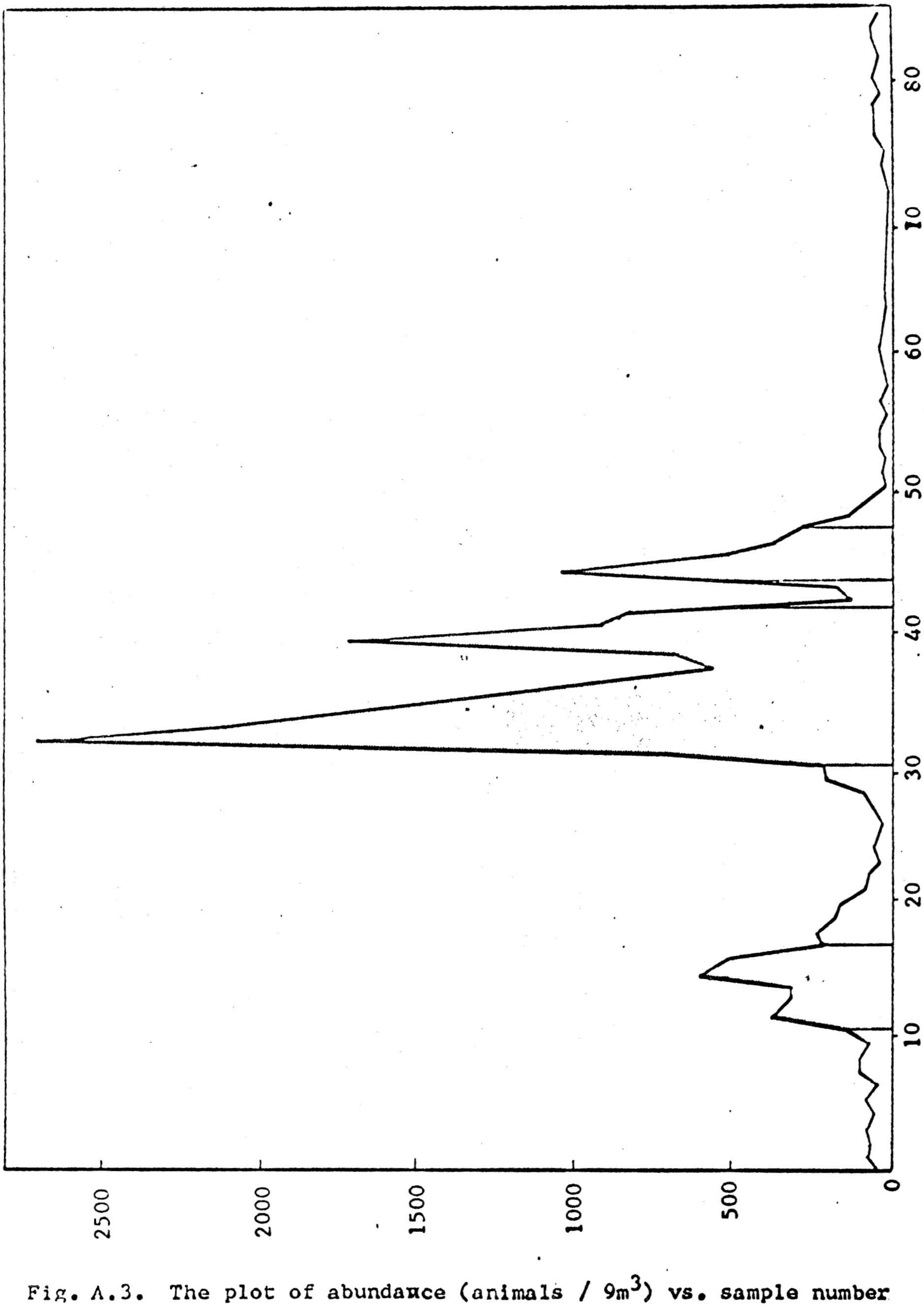

Fig. A.3. The plot of abundance (animals / $9m^3$) vs. sample number for nauplius in the Southern Sector.

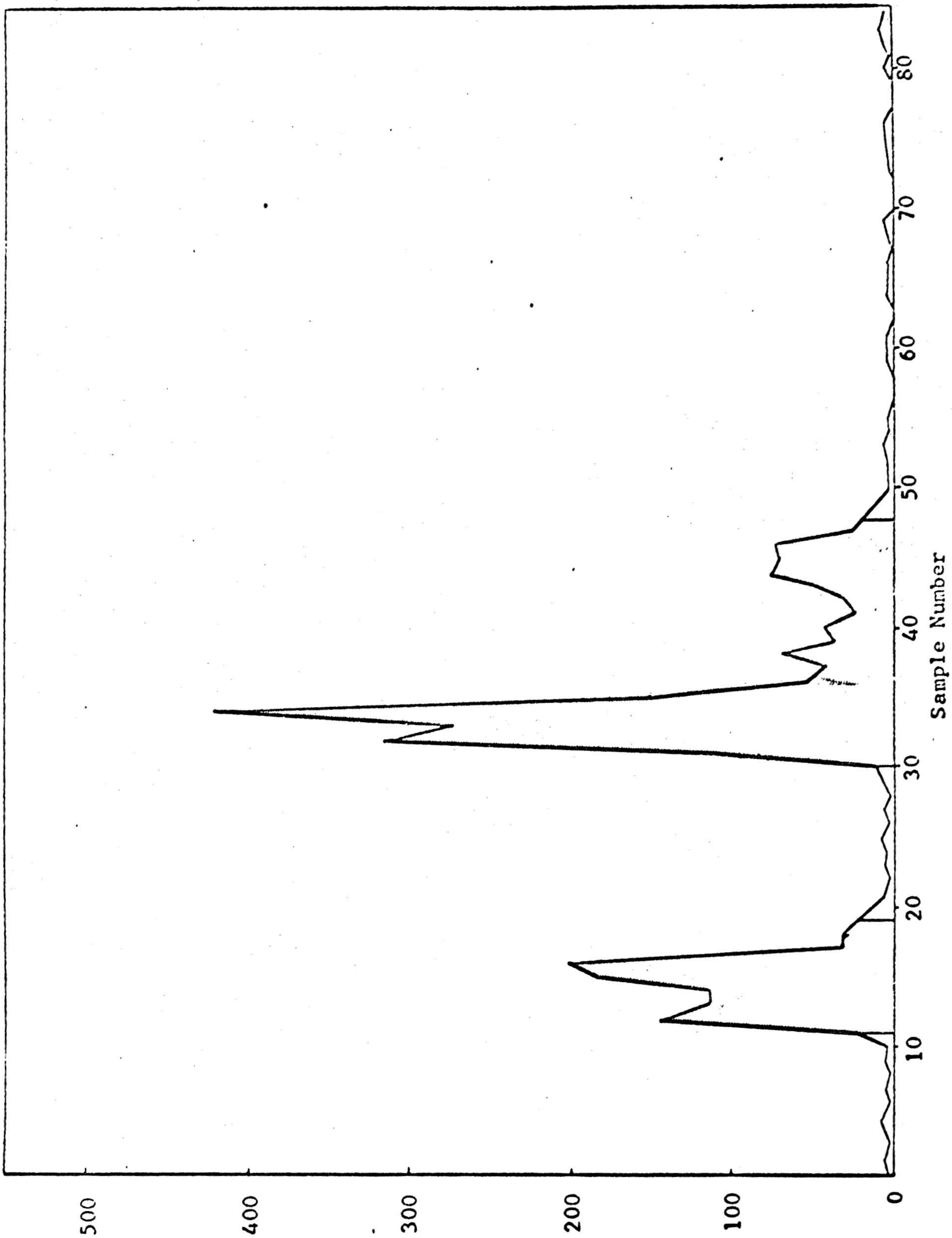

Fig. A.4. The plot of abundance (animals / $9m^3$) vs. sample number for cypris in the Southrrn Sector.

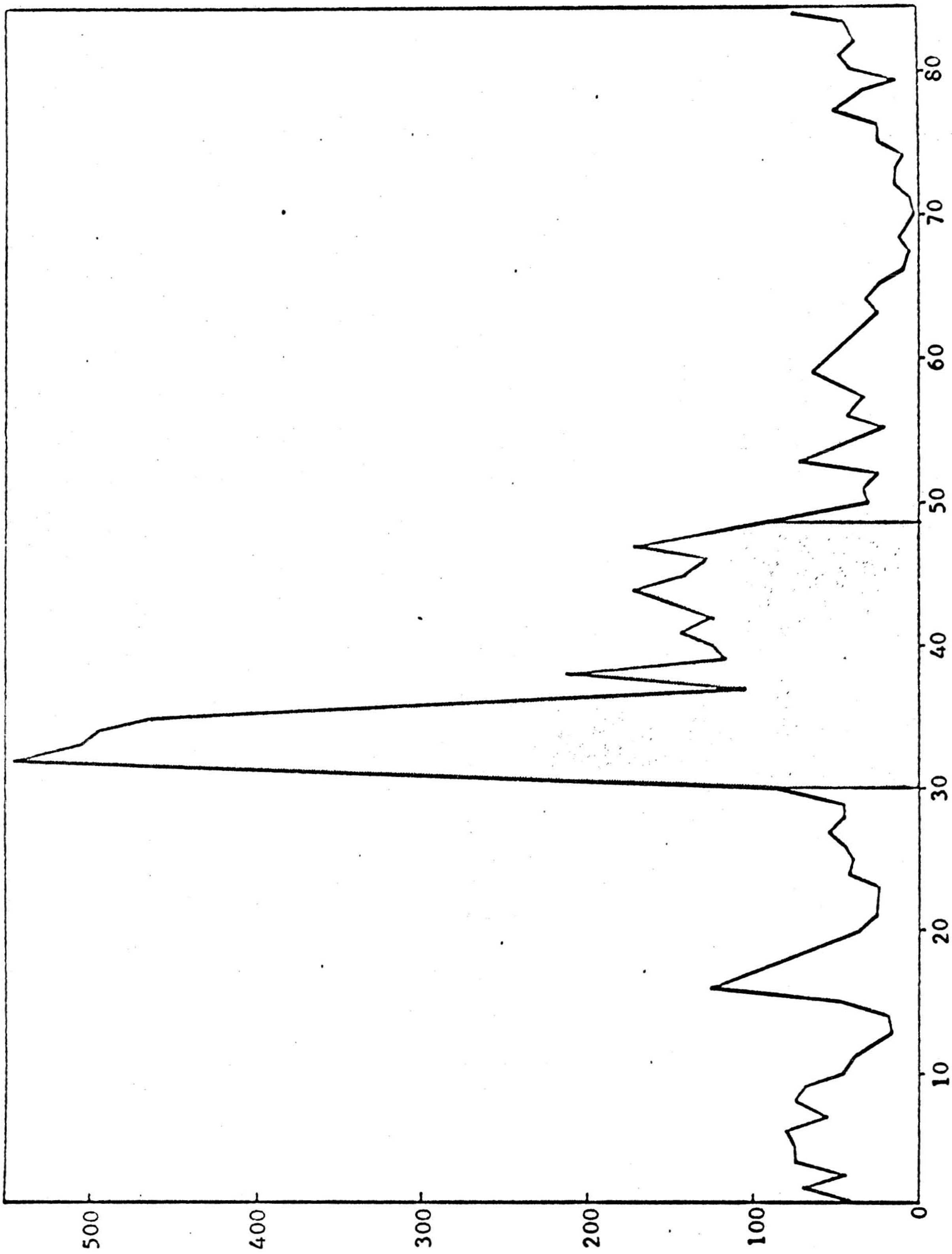

Fig. A.5. The plot of abundance (animals / $9m^3$) vs. sample number for zoea in the Southern Sector.

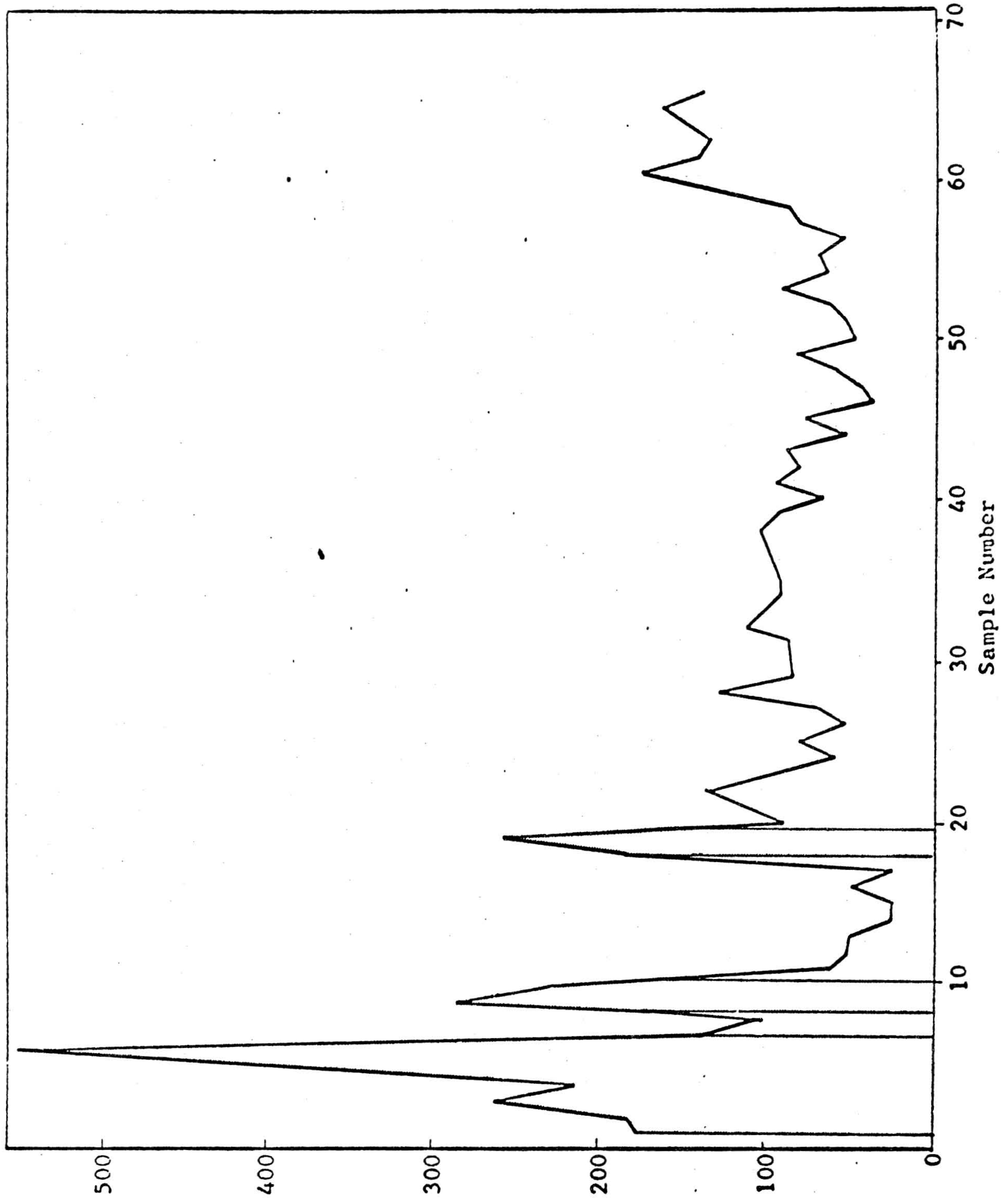

Fig. A.6. The plot of abundance (animals / $3m^3$) vs. sample number for zoea in the Middle Sector.

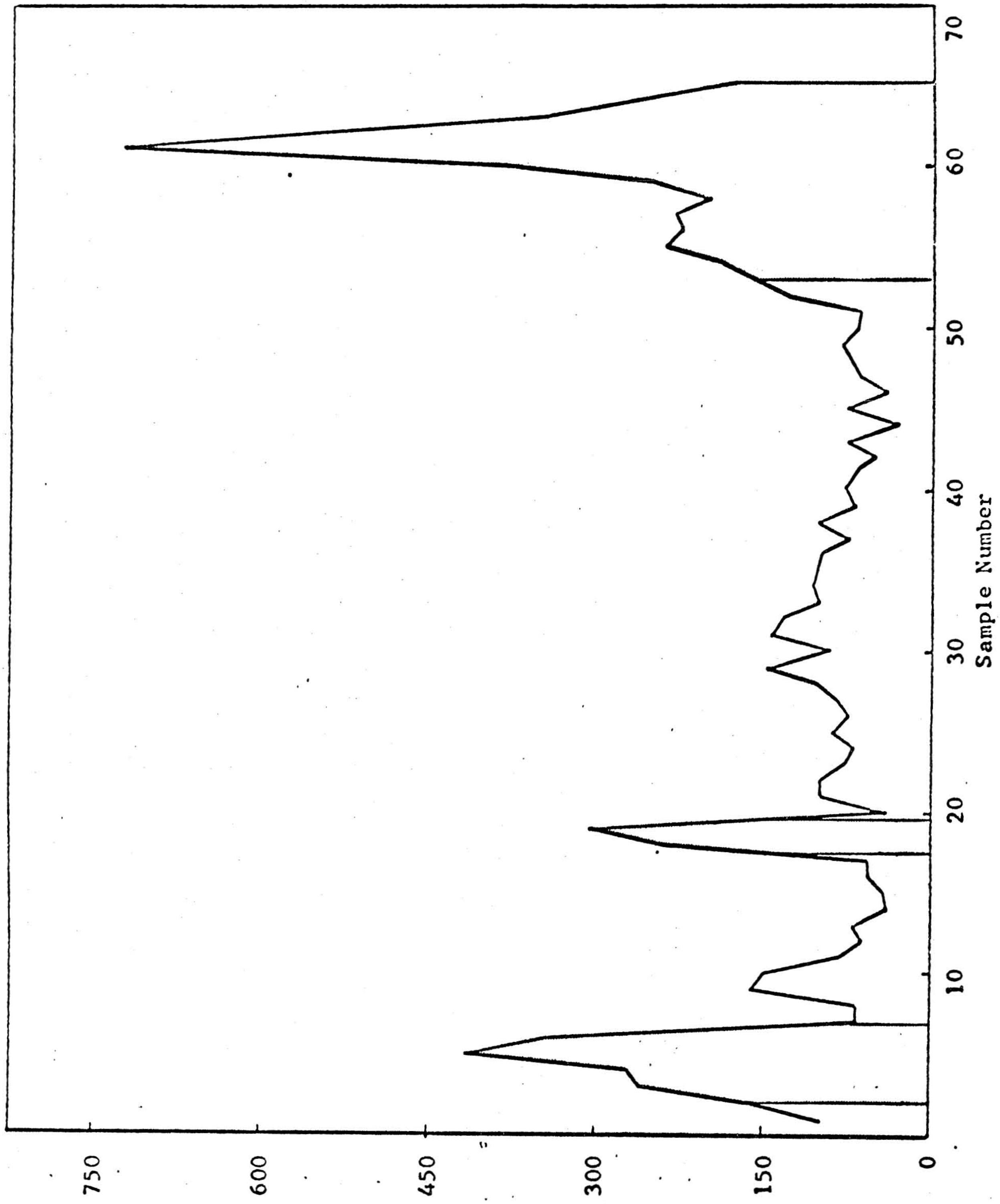

Fig. A.7. The plot of abundance (animals / $3m^3$) vs. sample number for Labidocera in the Middle Sector.

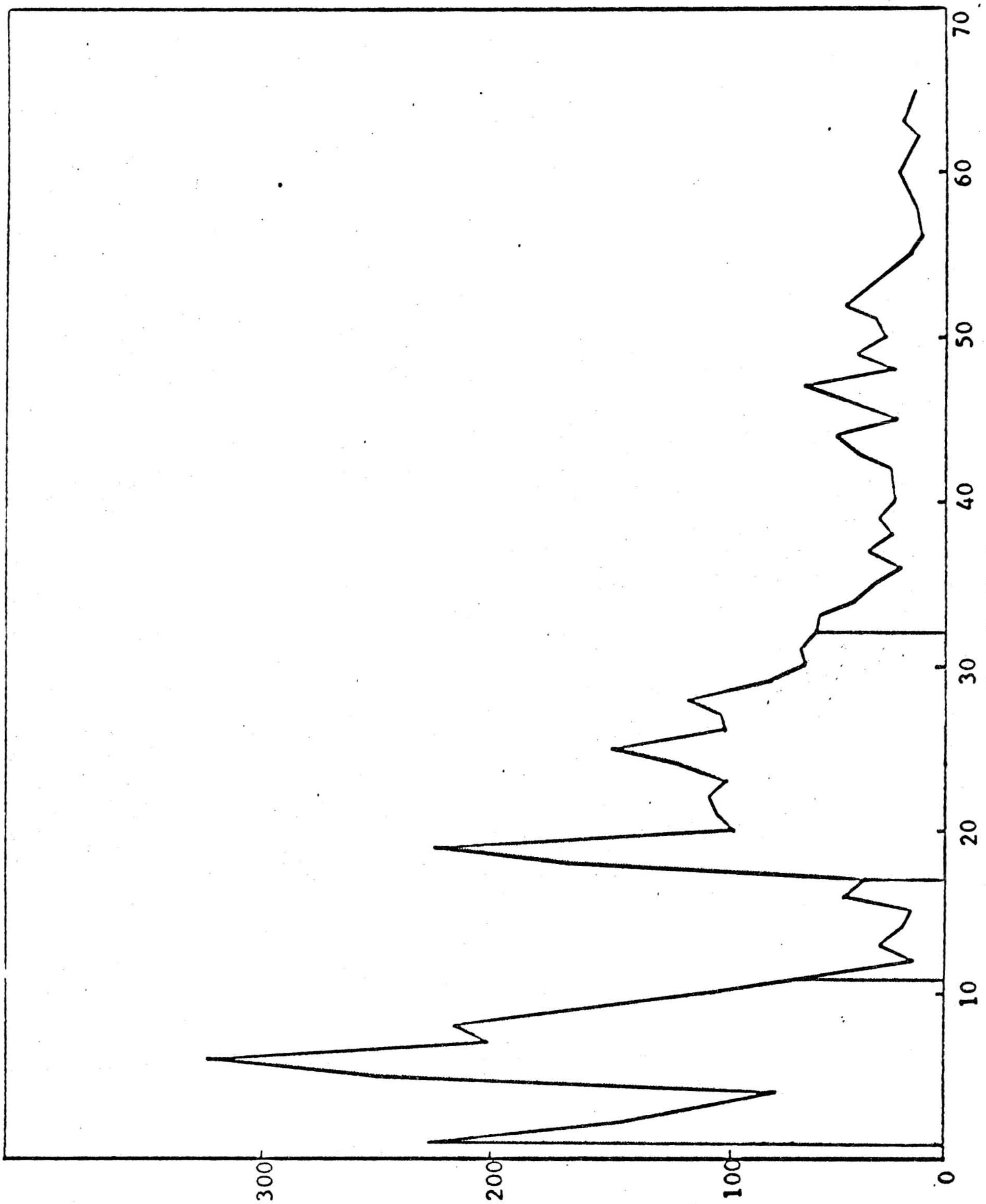

Fig. A.8. The plot of abundance (animals / $3m^3$) vs. sample number for mysis in the Middle Sector.

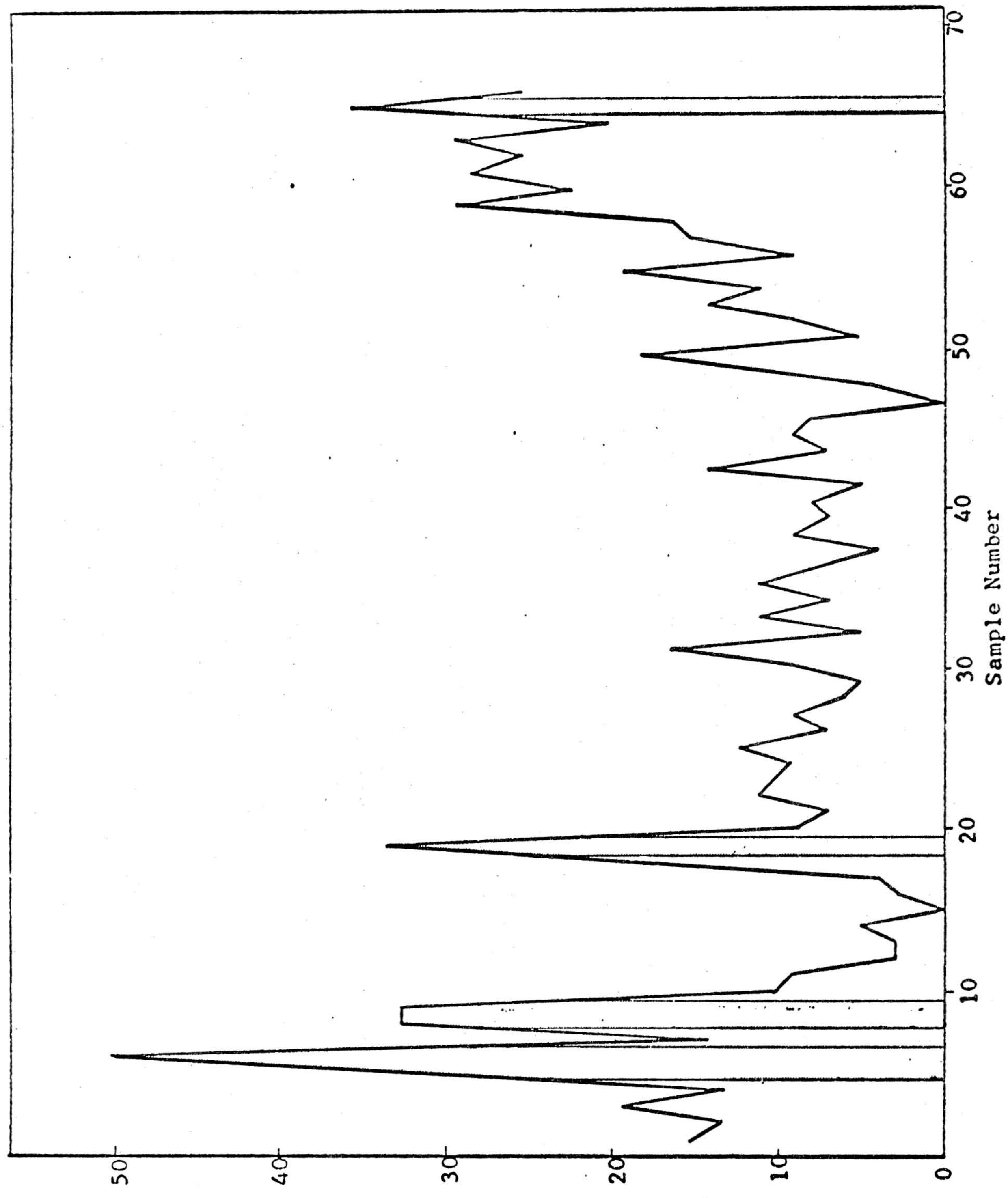

Fig. A.9. The plot of abundance (animals / $3m^3$) vs. sample number for alima in the Middle Sector.

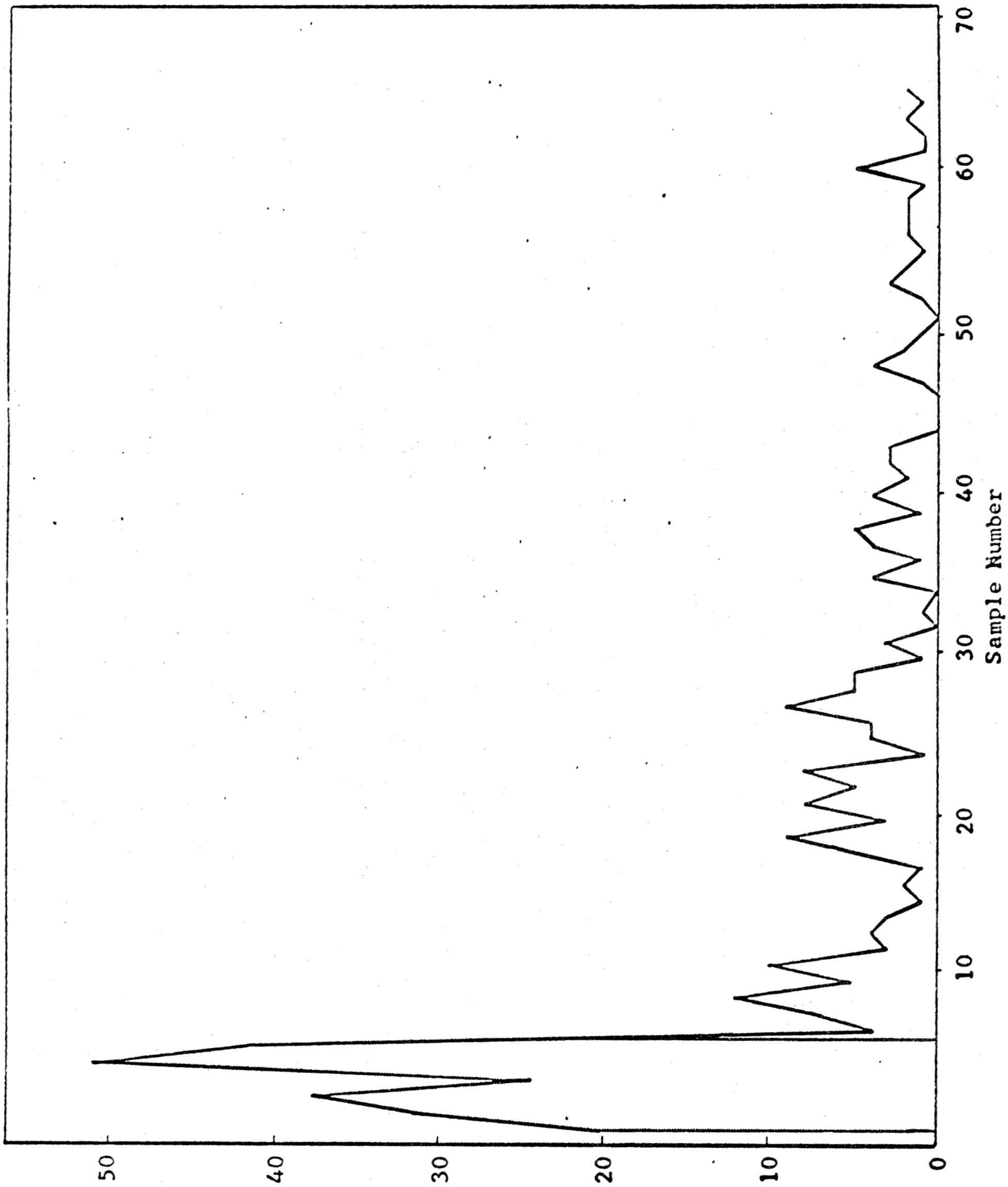

Fig. A.10. The plot of abundance (animals / $3m^3$) vs. sample number for Copilia in the Middle Sector.

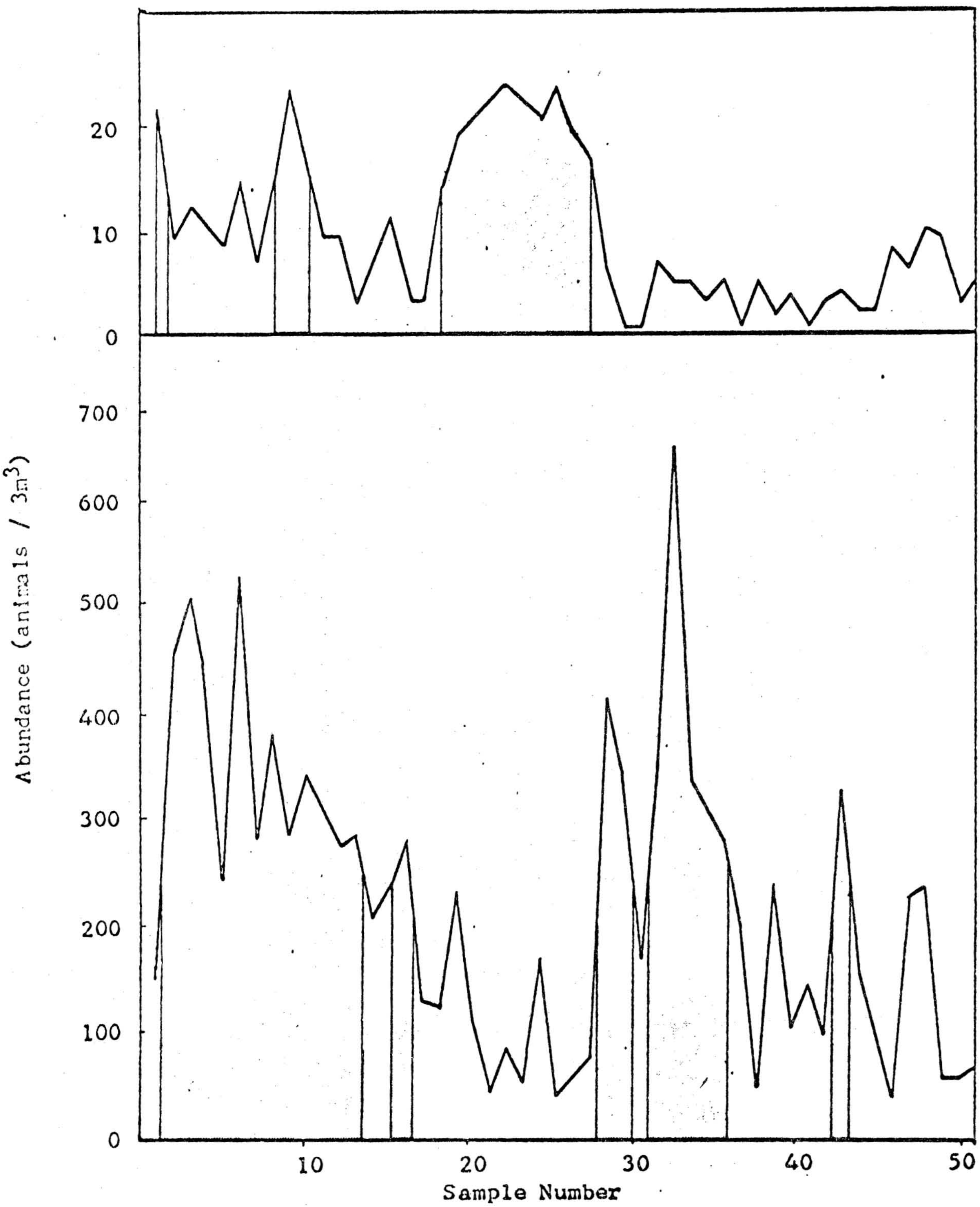

Fig. A.11. The plots of abundance vs. sample number for mysis (upper) and Lucifer (lower) in the North Sector.

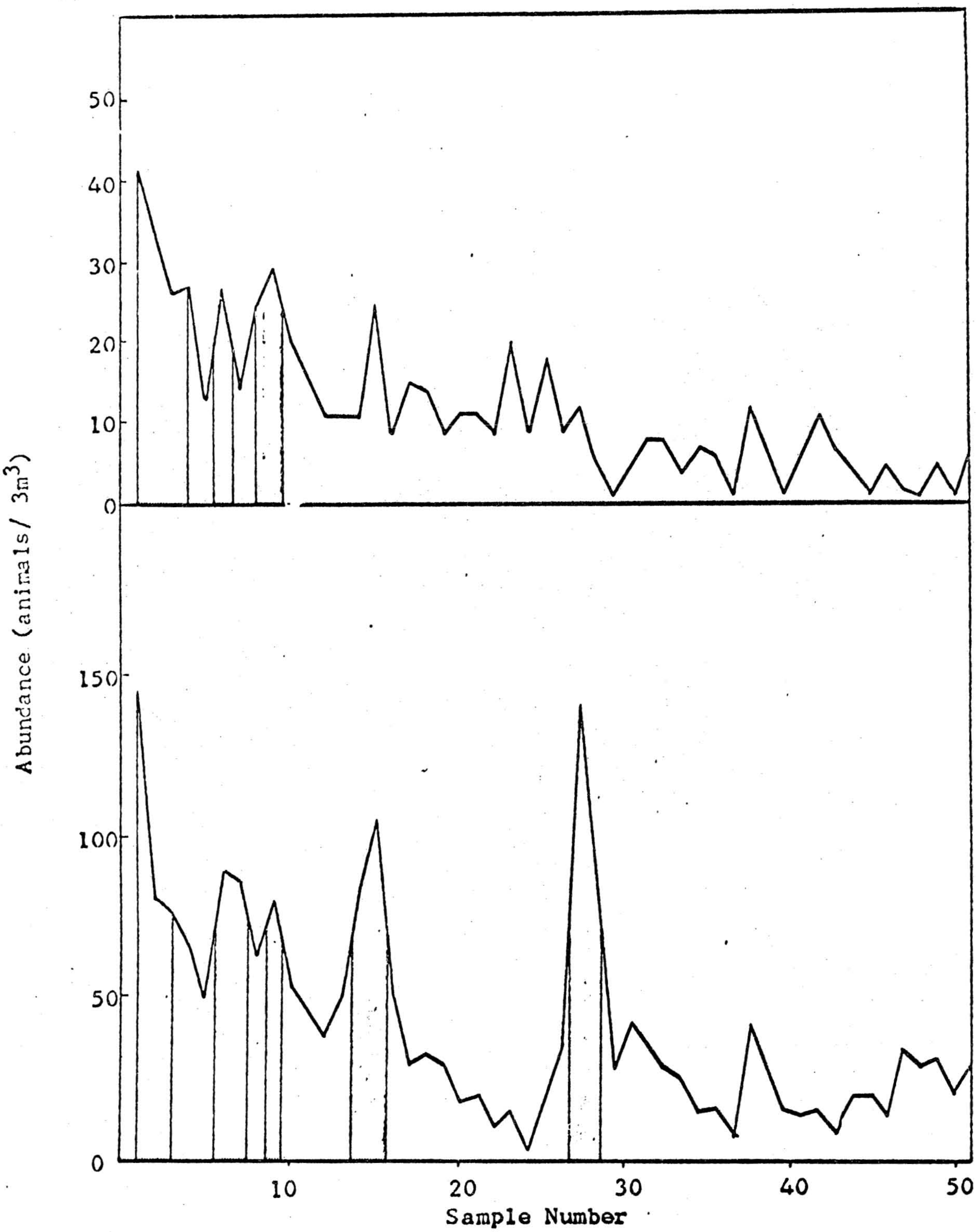

Fig. A.12. The plots of abundance vs. sample number for zoea (upper) and Labidocera (lower) in the North Sector.

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